Quarkonium physics at a fixed-target experiment with the proton and lead LHC beams

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Brookhaven National Laboratory, USA

with F. Fleuret (LLR), S.J. Brodsky (SLAC), . . .

Part I

A fixed-target experiment using the LHC beam(s): generalities

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Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (μb^{-1}.s^{-1})	$\mathcal{L}$ (pb^{-1}.y^{-1})
Liq. H_2	0.07	1	21	210
Liq. D_2	0.16	2	24	240
Be	1.85	9	60	600
Cu	8.96	64	40	400
W	19.1	185	30	300
Pb	11.35	207	16	160

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- Using **NA51**-like 1.2m-long liquid H_2 & D_2 targets, $\mathcal{L}_{H_2/D_2} \simeq 20$ fb$^{-1}y^{-1}$
- For comparison, PHENIX recorded lumi for Run9 pp at 200 GeV: 16 pb^{-1} & Run8 *d*Au at 200 GeV : 0.08 pb^{-1}

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P. Ballin *et al.*, **NIMB 267 (2009) 2952**

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Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (mb^{-1}.s^{-1})=$\int\mathcal{L}$ (nb^{-1}.yr^{-1})
Liq. H_2	0.07	1	28
Liq. D_2	0.16	2	34
Be	1.85	9	84
Cu	8.96	64	56
W	19.1	185	42
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- For comparison, Phenix recorded lumi for Run10
  AuAu at 200 GeV: 1.3 nb^{-1} & AuAu at 62 GeV: 0.11 nb^{-1}

Beam extraction

- **Beam extraction @ LHC**

… there are extremely promising possibilities to extract 7 TeV protons from the circulating beam by means of a bent crystal.

… The idea is to put a bent, single crystal of either Si or Ge (W would perform slightly better but needs substantial improvements in crystal quality) at a distance of $\simeq 7\sigma$ to the beam where it can intercept and deflect part of the beam halo by an angle similar to the one the foreseen dump kicking system will apply to the circulating beam.

… ions with the same momentum per charge as protons are deflected in a crystal with similar efficiencies

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Nuclear Instruments and Methods in Physics Research B 234 (2005) 31–39
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Strong crystalline fields – a possibility for extraction from the LHC

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If the crystal is positioned at the kicking section, the whole dump system can be used for slow extraction of parts of the beam halo, the particles that are anyway lost subsequently at collimators.

Part II

AFTER as a quarkonium observatory in *pp*

(constraining the glue at large x in the proton)

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  - and the good detectability of a dimuon pair

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PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

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W. J. Stirling
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(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) “soft,” (2) “hard,” and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the “soft”-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

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Z. Phys. C – Particles and Fields 38, 473–478 (1988)

J/ψ Production at large transverse momentum at hadron colliders

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[1] Cavendish Laboratory, University of Cambridge, Cambridge, CB3 0HE, England
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Received 7 October 1987

Abstract. We calculate J/ψ hadroproduction and emphasize the importance of the J/ψ signal as a measure of $b\bar{b}$ production via the decay $B \to \psi X$ and of the gluon structure function at low x via χ hadroproduction followed by $\chi \to \psi\gamma$ decay. We compare with UA1 data and data at ISR energies and make predictions for ψ production at TEVATRON energies.

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PHYSICAL REVIEW D VOLUME 48, NUMBER 11 1 DECEMBER 1993

ψ production in $\bar{p}N$ and π^-N interactions at 125 GeV/c and a determination of the gluon structure functions of the $\bar{p}$ and the π^-

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He Mao,[5] C. Hojvat,[2] D. Judd,[2,‡] S. Katsanevas,[1] R. D. Kephart,[2] C. Kourkoumelis,[1] P. Kraushaar,[4,§]
P. Lebrun,[3,*] P. K. Malhotra,[2,∥] A. Markou,[1] P. O. Mazur,[2] D. Nitz,[4] L. K. Resvanis,[1] D. Ryan,[3]
T. Ryan,[3,¶] W. Schappert,[3,**] D. G. Stairs,[3] R. Thun,[4] F. Turkot,[2] S. Tzamarias,[1,††] G. Voulgaris,[1]
R. L. Wagner,[2] D. E. Wagoner,[2,‡] W. Yang,[2] and Zhang Nai-jian[5]

(E537 Collaboration)

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[2]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
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[4]*University of Michigan, Ann Arbor, Michigan 48109*
[5]*Shandong University, Jinan, People's Republic of China*
(Received 9 February 1993)

We have measured the cross section for production of ψ and ψ' in $\bar{p}$ and π^- interactions with Be, Cu, and W targets in experiment E537 at Fermilab. The measurements were performed at 125 GeV/c using a forward dimuon spectrometer in a closed geometry configuration. The gluon structure functions of the $\bar{p}$ and π^- have been extracted from the measured $d\sigma/dx_F$ spectra of the produced ψ's. From the $\bar{p}$W data we obtain, for $\bar{p}$, $xG(x)=(2.15\pm0.7)[1-x]^{(6.83\pm0.5)}[1+(5.85\pm0.95)x]$. In the π^- case, we obtain, from the W and the Be data separately, $xG(x)=(1.49\pm0.03)[1-x]^{(1.98\pm0.06)}$ (for π^-W), $xG(x)=(1.10\pm0.10)[1-x]^{(1.20\pm0.20)}$ (for π^-Be).

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  - Yet, very sensitive on $g(x, Q^2)$ where it is not well known

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When hadroproduction casts doubt on lepto/photo-production

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Volume 191, number 1,2 PHYSICS LETTERS B 4 June 1987

INELASTIC LEPTOPRODUCTION OF J/ψ AS A PROBE OF THE SMALL-x BEHAVIOUR OF THE GLUON STRUCTURE FUNCTION

A.D. MARTIN, C.-K. NG and W.J. STIRLING

Department of Physics, University of Durham, Durham DH1 3LE, UK

Received 19 February 1987

The differential cross section $d\sigma/dx$ for the inelastic photoproduction of J/ψ is predicted, via the subprocess $\gamma g \to \psi g$, to be sharply peaked at a small value, x_{peak}, of x and, even more remarkably, the integrated $\gamma N \to \psi X$ cross section is, up to a calculable numerical constant, essentially the proton–gluon distribution $xG(x)$ at $x \simeq x_{\text{peak}}$. Cross section measurements at HERA may thus provide a direct determination of $G(x)$ for $x \sim 10^{-3}$. Inelastic J/ψ events arising from $b\bar{b}$ production are also studied.

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Volume 258, number 3,4 PHYSICS LETTERS B 11 April 1991

Inelastic J/ψ production in deep inelastic scattering from hydrogen and deuterium and the gluon distribution of free nucleons

New Muon Collaboration (NMC)

Received 10 November 1990

We present results on inelastic J/ψ production from muon interactions with hydrogen and deuterium at an incident muon energy of 280 GeV The measured cross section ratio per nucleon for muon-induced J/ψ production in deuterium and hydrogen was found to be $R(D_2/H_2)=1\ 01\pm0.15$ The colour singlet model is shown to provide a good description of the observed differential cross section apart from a normalisation factor The comparison between the observed cross section and the colour singlet model prediction allows the extraction of the gluon structure function $G(x)$ of the nucleon The momentum fraction x of the nucleon carried by the gluon is measured in the range of $x=[0\ 02, 0\ 30]$ The normalised gluon distribution of free nucleons thus found can be parametrised as $xG(x)=\frac{1}{2}(\eta+1)(1-x)^{\eta}$, with $\eta=5.1\pm0\ 9$(stat)

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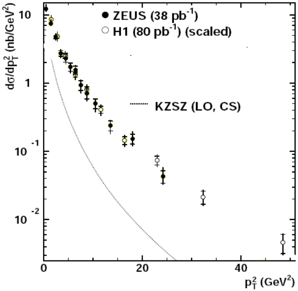

(we are in 1996 !)

M.Kramer Nucl.Phys.B459:3 1996
H1,EPJC 25, 2,2002; ZEUS, EPJC 27, 173, 2003

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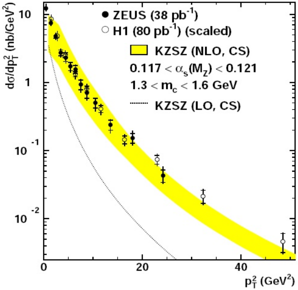

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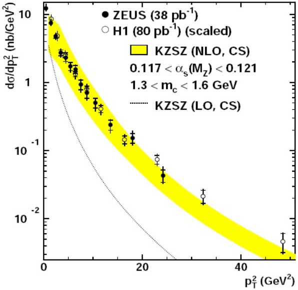

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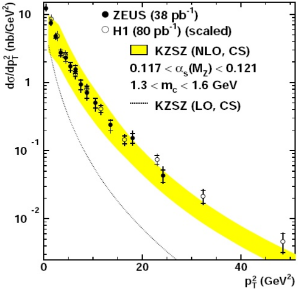

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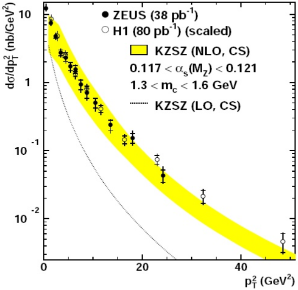

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- This issue needs also to be addressed when discussing EIC . . .

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- To put an end to production controversies (since 1995 !), we need
  - a study of direct J/ψ yield (χ_c only measured in *pp* by CDF and PHENIX)
  - a study of direct $\Upsilon(nS)$ (χ_b only measured in *pp* by CDF (1 point))
  - a study of the polarisation of direct yields

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- The latter are **potentially better probes** of glue in *pp*

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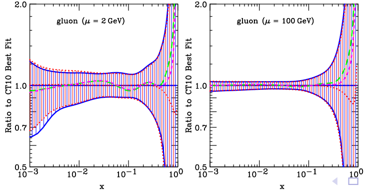

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- Use of *pp* vs *pd* $\rightarrow$ access to the
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cf. E866, Phys. Rev. Lett. 100 062301 (2008)

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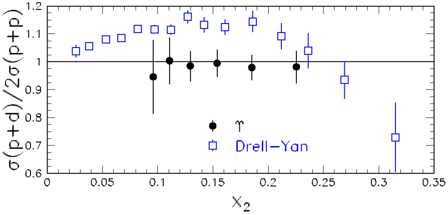

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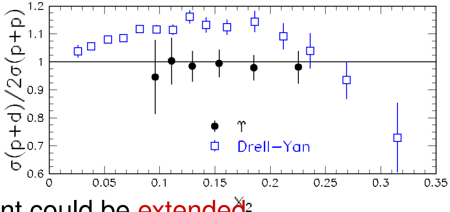

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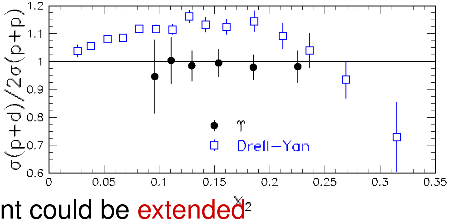

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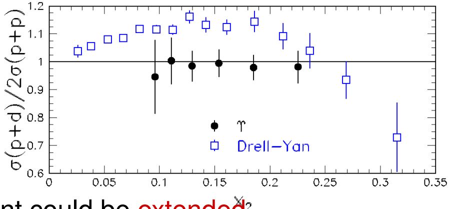

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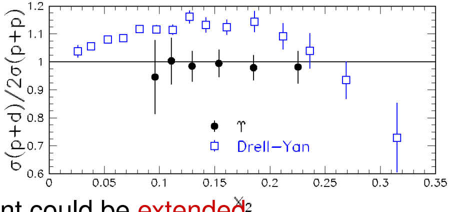

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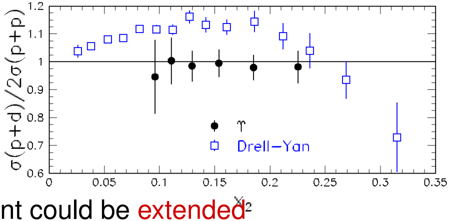

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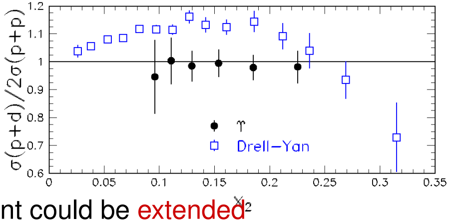

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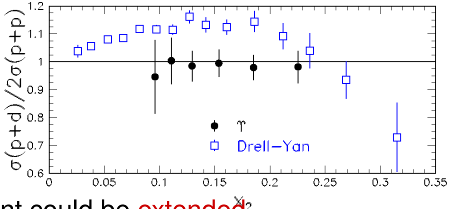

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More on quarkonium as a probe...

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Double J/ψ production: a probe of gluon polarization?

S.P. Baranov[1], H. Jung[2]

[1]P.N.Lebedev Physical Institute, Moscow 117924, Russia
[2]III. Physikalisches Institut, Lehrstuhl B, RWTH Aachen, Germany

Received: 5 July 1994/Revised version: 5 October 1994 Z. Phys. C 66, 647–651 (1995)

Abstract. We consider the process of direct simultaneous production of two J/ψ particles and discuss the possibility that it can be used as a tool to measure the gluon polarization in the colliding particles.

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PHYSICAL REVIEW D VOLUME 49, NUMBER 9 1 MAY 1994

Associated $J/\psi + \gamma$ production as a probe of the polarized gluon distribution

M. A. Doncheski*
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706

C. S. Kim
Department of Physics, Yonsei University, Seoul 120, Korea
(Received 15 March 1993)

Associated production of J/ψ and a γ has recently been proposed as a clean probe of the gluon distribution. The same mechanism can be used to probe the polarized gluon content of the proton in polarized proton-proton collisions. We study $J/\psi + \gamma$ production at both polarized fixed target and polarized collider energies.

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Pair production of J/ψ as a probe of double parton scattering at LHCb

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A. Kulesza‡
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We argue that the recent LHCb observation of J/ψ–pair production indicates a significant contribution from double parton scattering, in addition to the standard single parton scattering component. We propose a method to measure the double parton scattering at LHCb using leptonic final states from the decay of two prompt J/ψ mesons.

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- Double J/ψ, $J/\psi + \gamma$, $J/\psi + D$, ... can of course be studied with AFTER

Part III

AFTER as a quarkonium observatory in *pA*

(Precision analysis of Cold Nuclear Matter Effects)

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This calls for different measurements to (in)validate factorization

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  - not to mention ratio with open charm, Drell-Yan, etc ...

Part IV

AFTER as a quarkonium observatory in *PbA*

(the quest for sequential suppression)

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- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most
    i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}–
    that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence too !
  - not clear what v_2 tells us

A Fixed Target ExpeRiment: a quarkonium observatory in *PbA*

- The excellent capabilities in *pA* should help
  - to reduce the CNM uncertainties
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- As STAR people suggested, why not to look for gluon quenching
  in J/ψ+hadron correlations vs. centrality
  (I suspect that we need a good *pA* baseline)

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Part V

AFTER as a quarkonium observatory in polarised collisions

(the quest for gluon spin contributions)

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- The beam may become transversely polarised during the crystal extraction

  M. Ukhanov, Nucl. Instrum. Meth. A 582 (2007) 378.

  $\rightarrow$ to be experimentally checked ...

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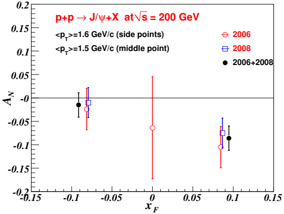

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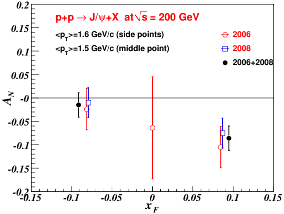

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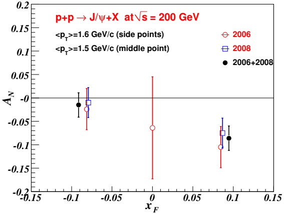

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- At $x_F > 0$, the gluon from the $p^{\uparrow}$ has a larger x_B
- It knows more about the proton spin than at low $x_B \rightarrow$ SSA grows

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- In general, the backward region is the most favourable allowing for measurements in the large *x* region of the polarised nucleon

Part VI

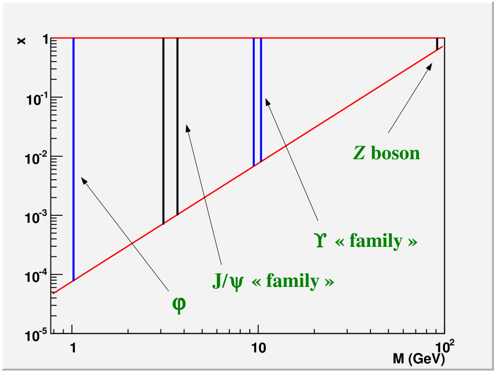
More with AFTER

(Drell-Yan, jet and W/Z)

A Fixed Target ExpeRiment

A dilepton observatory

- Region in x probed by dilepton production as function of $M_{\ell\ell}$



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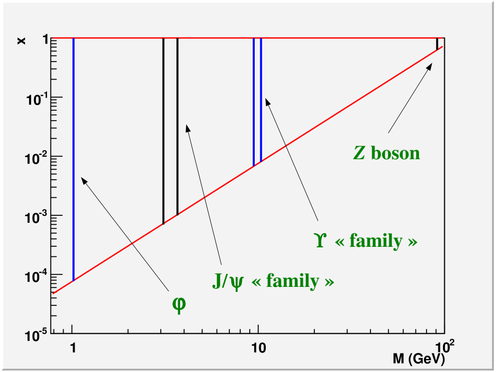

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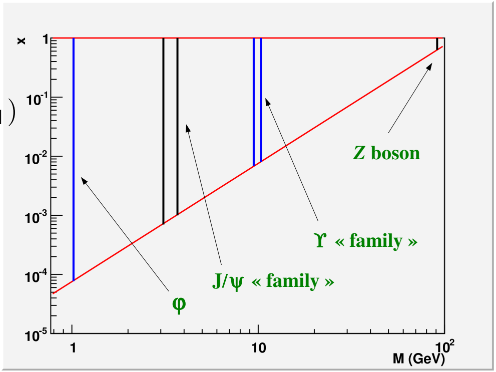

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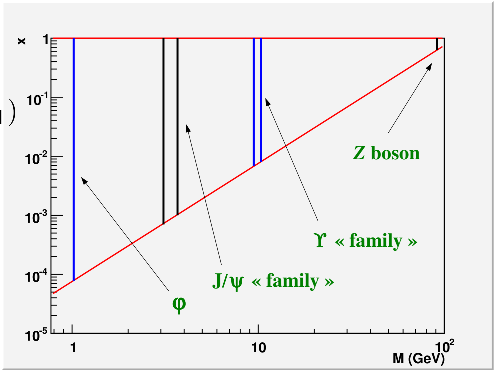

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"backward" region

→ sea-quark asymetries
via p and d studies

- at large(est) x: backward ("easy")

- at small(est) x: forward (need to stop the (extracted) beam)

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A dilepton observatory

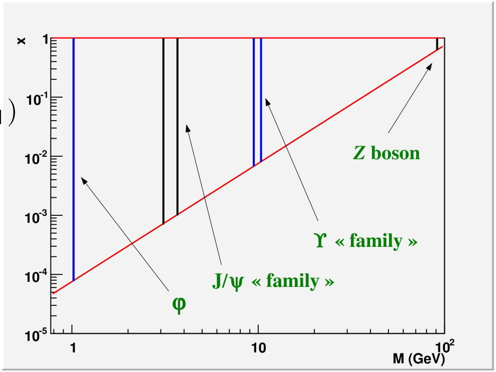
- Region in x probed by dilepton production as function of $M_{\ell\ell}$
  - → Above $c\bar{c}$: $x \in [10^{-3}, 1]$
  - → Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$

Note: $x_{target} (\equiv x_2) > x_{projectile} (\equiv x_1)$
"backward" region

→ sea-quark asymetries
via p and d studies

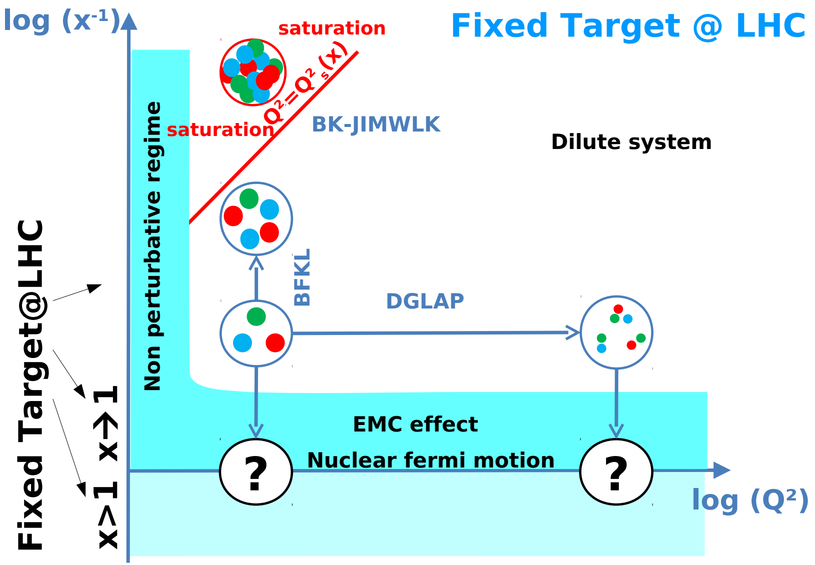
- at large(est) x: backward ("easy")

- at small(est) x: forward (need to stop the (extracted) beam)

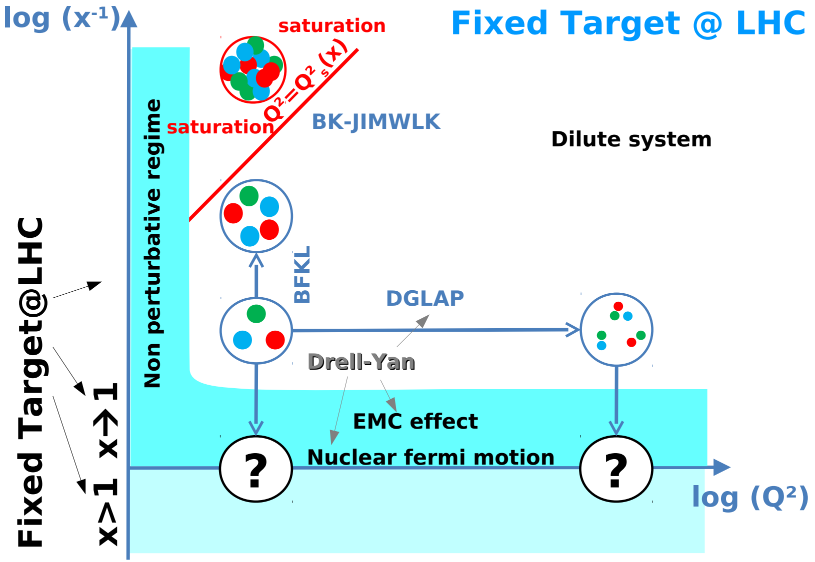


- To do: to look at the rates to see how competitive this will be

Overall


Fixed Target @ LHC
log (x⁻¹)
saturation
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
BFKL
DGLAP
Fixed Target@LHC
x→1
x>1
EMC effect
Nuclear fermi motion
?
?
log (Q²)

Overall



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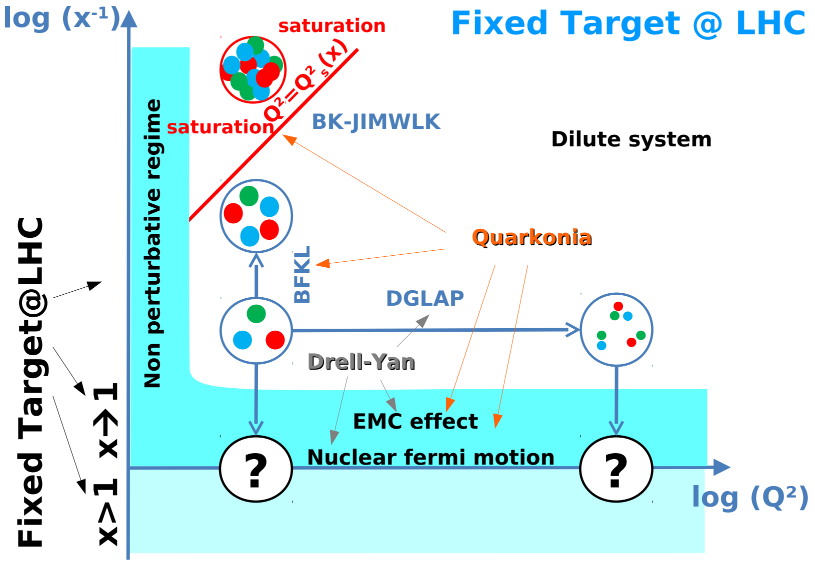
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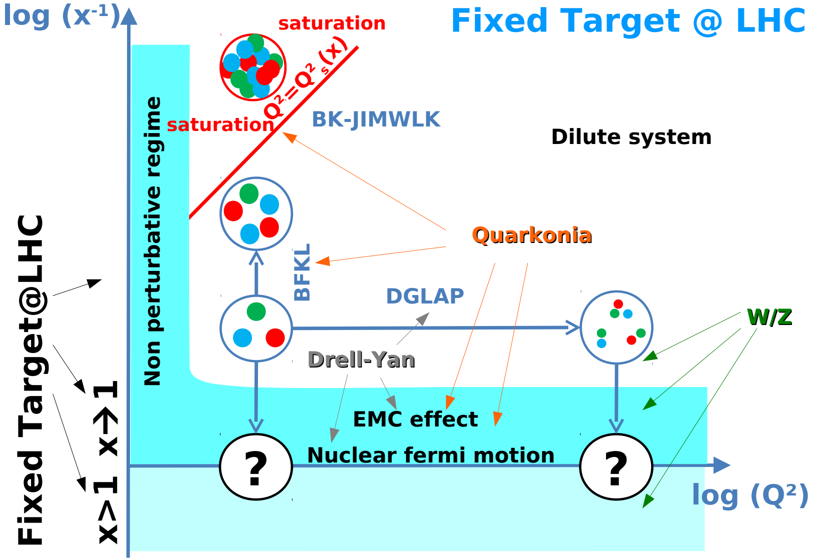

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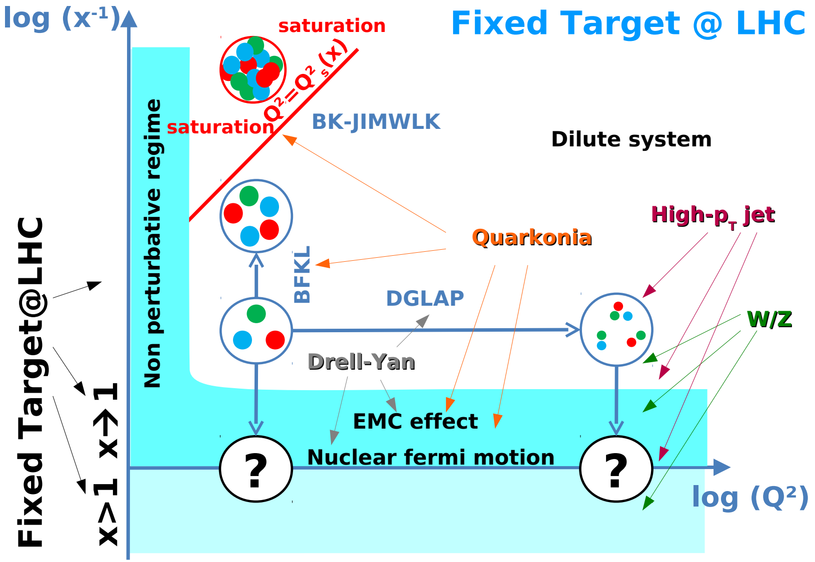

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Part VII

AFTER as photon-proton collider

One exotic illustration of the potentialities:

Ultra-peripheral collisions

A Fixed Target ExpeRiment

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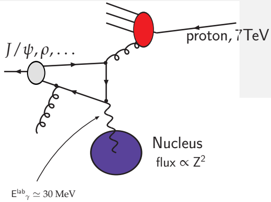
Ultra-peripheral collisions



Inelastic photoproduction of J/ψ via UPC*

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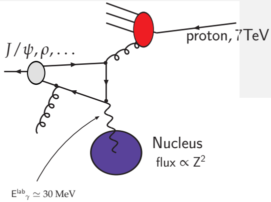

Inelastic photoproduction of J/ψ via UPC*

Thanks to the boost: $W^{max}_{\gamma+p}$ for a coherent photon emission (Z^2 fact.) can be as high as 25 GeV !

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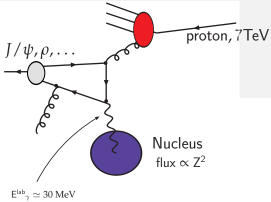

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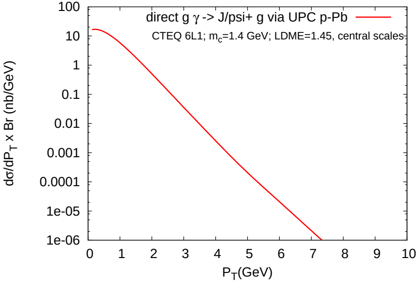

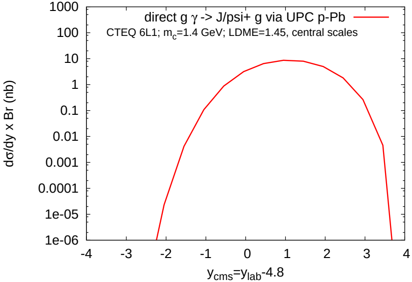

Disclaimer: these numbers suppose a dedicated trigger and are preliminary

A photon-proton collider at the LHC ?

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- True also for diffractive J/ψ photoproduction
- Handle on gluons (not sure though that one can compete in some way with EICs)

Z. Phys. C 76, 231–239 (1997)

ZEITSCHRIFT FÜR PHYSIK C

Diffractive J/ψ photoproduction as a probe of the gluon density

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Abstract. We use perturbative QCD, beyond the leading $\ln Q^2$ approximation, to show how measurements of diffractive J/ψ production at HERA can provide a sensitive probe of the gluon density of the proton at small values of Bjorken x. We estimate both the effect of the relativistic motion of the c and $\bar{c}$ within the J/ψ and of the rescattering of the $c\bar{c}$ quark pair on the proton. We find that the available data for diffractive J/ψ photoproduction can discriminate between the gluon distributions of the most recent sets of partons.

Part VIII

Conclusion and outlooks

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